Eleventh U.S. National Conference on Earthquake Engineering
Integrating Science, Engineering & Policy
June 25-29, 2018
Los Angeles, California

GUIDELINES ON NONLINEAR DYNAMIC ANALYSIS FOR SEISMIC DESIGN OF STEEL MOMENT FRAMES

G. G. Deierlein[1], D. Lignos[2], S. Bono[3], A. Kanvinde[4]

ABSTRACT

Nonlinear dynamic (response history) analysis is being used increasingly in design practice for the performance-based seismic design of buildings. In contrast to nonlinear static analysis, dynamic analyses require more explicit modeling of cyclic response including strength and stiffness degradation as well as special consideration to selection and scaling of ground motions, definition of viscous damping, and other dynamic effects. To help bridge the gap between state-of-the-art in research and practice, the National Institute of Standards and Technology has funded ATC-114 project to develop improved modeling criteria and guidelines for nonlinear dynamic analysis. The guidelines address both overall considerations, such as recommendations for modeling floor diaphragms and equivalent viscous damping, along with component modeling criteria that are specific to steel moment frame systems. Nonlinear analysis provisions for steel moment frames include new parameters for concentrated hinge models to facilitate modeling of strength and stiffness degradation under random cyclic loading. The new parameters are calibrated to testing and detailed finite element analyses of beam-to-column connections and columns subjected to bending and axial loads. The guidelines also include recommendations for modeling fracture-critical welded connections using fiber-type hinge models. An example analysis of a four-story steel moment frame building is included to illustrate application of the guidelines, following the new ASCE 7-16 requirements for nonlinear response history analysis.
.

GUIDELINES ON NONLINEAR DYNAMIC ANALYSIS FOR SEISMIC DESIGN OF STEEL MOMENT FRAMES

G. G. Deierlein[1] , D. Lignos [2], S. Bono[3], A. Kanvinde[4]

ABSTRACT

Nonlinear dynamic (response history) analysis is being used increasingly in design practice for the performance-based seismic design of buildings. In contrast to nonlinear static analysis, dynamic analyses require more explicit modeling of cyclic response including strength and stiffness degradation as well as special consideration to selection and scaling of ground motions, definition of viscous damping, and other dynamic effects. To help bridge the gap between state-of-the-art in research and practice, the National Institute of Standards and Technology has funded ATC-114 project to develop improved modeling criteria and guidelines for nonlinear dynamic analysis. The guidelines address both overall considerations, such as recommendations for modeling floor diaphragms and equivalent viscous damping, along with component modeling criteria that are specific to steel moment frame systems. Nonlinear analysis provisions for steel moment frames include new parameters for concentrated hinge models to facilitate modeling of strength and stiffness degradation under random cyclic loading. The new parameters are calibrated to testing and detailed finite element analyses of beam-to-column connections and columns subjected to bending and axial loads. The guidelines also include recommendations for modeling fracture-critical welded connections using fiber-type hinge models. An example analysis of a four-story steel moment frame building is included to illustrate application of the guidelines, following the new ASCE 7-16 requirements for nonlinear response history analysis.

Introduction

As part of its ongoing efforts to advance the practice of performance-based seismic design, the National Institute of Standards and Technology (NIST) funded a project through the Applied Technology Council (ATC) to develop comprehensive guidelines for the use of nonlinear dynamic analysis in design. In contrast to previous efforts that have focused on criteria for nonlinear analysis to evaluate existing buildings, this recent project was primarily focused on guidelines for the seismic design and assessment of new buildings. Although not exclusively limited to new buildings, the modeling guidelines have greater emphasis towards seismic resisting systems that are more common in new buildings with structural components that are designed for reliable inelastic behavior. The guidelines emphasize cyclic and dynamic response characteristics that are important for nonlinear dynamic analysis, which have not been given as much attention in previously developed guidelines that have emphasized nonlinear static (pushover) analysis.

---

[1] Professor, Blume Earthquake Engrg Center, Stanford University, Stanford, CA 94305 (ggd@stanford.edu)
[2] Associate Professor, EPFL ENAC IIC RESSLab, Swiss Federal Institute of Technology, Lausanne
[3] Senior Staff II - Structures, Simpson Gumpertz and Heger Inc., San Francisco, CA
[4]Professor, Dept. of Civil and Environmental Engineering, University of California, Davis, CA

Deierlein, G.G., Lignos, D., Bono, S., Kanvinde, A., Guidelines on Nonlinear Dynamic Analysis for Seismic Design of Steel Moment Frames. *Proceedings of the 11th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

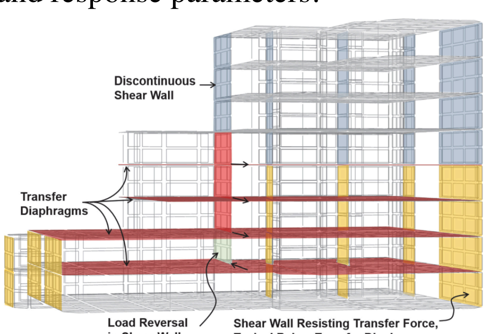
With their emphasis towards new buildings, these guidelines are intended to be used in conjunction with related standards and criteria for the design of new buildings, including the new Chapter 16 requirements of ASCE 7-16 [1] and recent updates to performance-based seismic design guidelines for tall buildings [2,3]. The guidelines will also support other applications for nonlinear analysis, such as evaluation of existing buildings using ASCE 41 [4] or seismic performance assessment using FEMA P58 or P695 [5,6]. Further, the scope of the guidelines is designed to complement, rather than replicate or replace, information from other related standards and guidelines for seismic design (e.g., from other NIST or FEMA reports on specific topics or from AISC or ACI standards).

The analysis guidelines are organized into a Part I and Part II, where the Part I document [7] covers guidelines that are generally applicable to the analysis of any system type, and the Part II documents include guidelines for specific system types. The first phase of the NIST effort has supported the development of Part II guidelines for steel [8] and concrete [9] moment frame systems. It is anticipated that future Part II guidelines will be developed for concrete shear walls, steel braced-frames, and other types of systems.

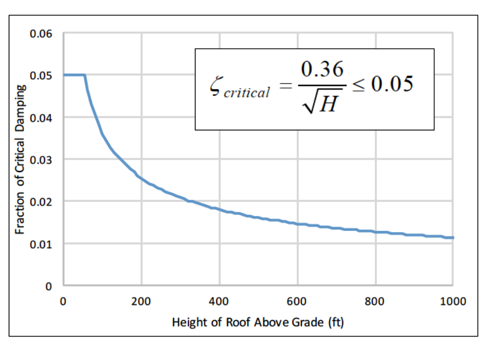
Highlights of Part I – General Guidelines

The Part I guidelines are organized around the following topics:

- Overview of nonlinear modeling and analysis procedures for common building systems
- General modeling requirements, including representation of the complete structural resisting system, seismic mass, gravity loads, geometric nonlinearities, torsion, and expected material properties.
- Modeling guidance for floor diaphragms and collectors (Fig. 1a), including recommendations for assumed stiffness of concrete and composite slab systems.
- Modeling of viscous damping (Fig. 1b) and its role in representing energy dissipation that exists in the system but is not otherwise modeled by hysteretic response of deformation-controlled (yielding) elements.
- Modeling of foundations and soil-structure interaction
- General requirements and recommendations for nonlinear static (pushover) and dynamic (response history) analyses.
- Calculation and evaluation of drift and other acceptance criteria for deformation and force controlled components, including consideration of uncertainties in seismic demands and response parameters.



(a)



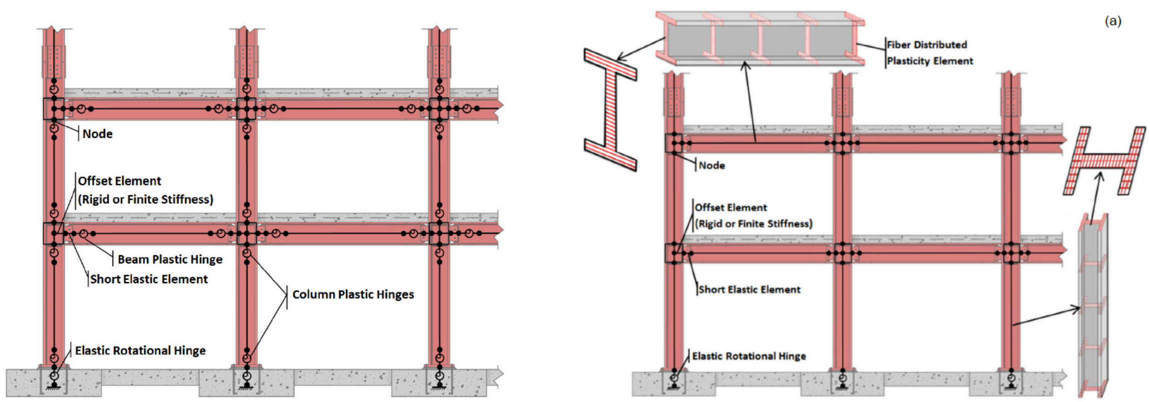
(b)

Figure 1: General guidelines (a) diaphragm modeling, (b) recommended viscous damping

Highlights of Part II – Steel Moment Frame Guidelines

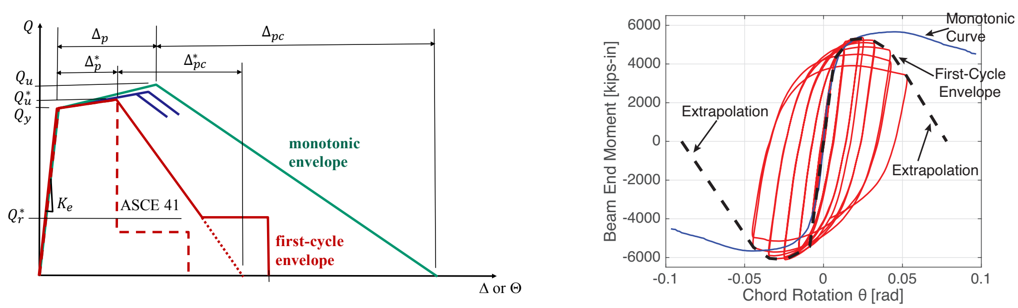
The Part IIa guidelines are organized around the following topics:

- Overview of expected structural behavior and failure modes in seismically design steel moment frames.
- Overview of nonlinear analysis models for steel moment frames and their primary components (beams, columns, column splices, beam-column panel zones, floor diaphragms and collectors, secondary 'gravity' systems.
- Concentrated hinge models (Fig. 2a) for beams, columns, and composite beam-column connections, including new parameters to characterize monotonic backbone and cyclic envelope models (Fig. 3) [10].
- Fiber type section and element models (Fig. 2b), including recommendations for material models, hinge lengths, and localized reduced beam section and connection yielding.
- Continuum finite element models with recommendations for modeling of geometric imperfections, residual stresses, post-buckling response, and strain limits for fracture and low-cycle fatigue.
- Modeling of pre-Northridge (fracture critical) welded connections and column splices, using critical fiber stress limits based on fracture mechanics.



(a) (b)

Figure 2: Idealize frame analysis models (a) concentrated hinge, (b) distributed fiber-type model

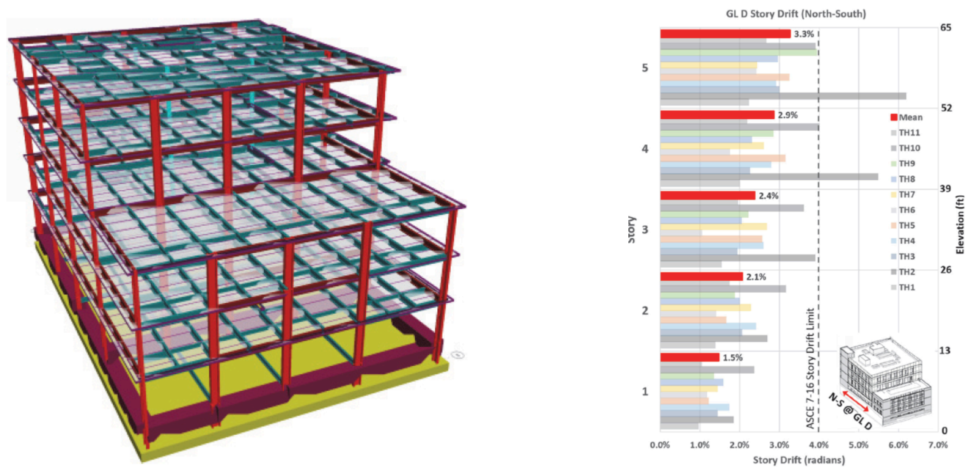


(a) (b)

Figure 3: Component models (a) generalized force-displacement, (b) montonic vs. first-cycle envelope

Illustrative Steel Moment Frame Building Analysis

The nonlinear analysis guidelines are illustrated in an evaluation of a 5-story steel moment frame building evaluated in accordance with the new Chapter 16 of ASCE 7-16 [1], see Fig. 4.



(a) (b)

Figure 4: Case study building (a) 3-D analysis model, (b) drift demands under MCE_R intensity motions

Acknowledgements

The analysis guidelines were developed by the Applied Technology Council (ATC, Project 114) and supported by a task order project under National Institute of Standards and Technology (NIST) Contract SB1341-13-CQ-0009. The authors and gratefully acknowledge: co-authors and project review panel of the NIST guidelines; Jon Heintz, Ayse Hortacsu, Veronica Cedillos and ATC colleagues for managing the project and editing the final guidelines; and Steven L. McCabe and colleagues at NIST for their input and guidance throughout the project development process.

References

1. ASCE, *Minimum Design Loads for Buildings and Other Structures, ASCE/SEI 7-16,* American Society of Civil Engineers, Reston, Virginia, 2016.
2. PEER, *Guidelines for Performance-Based Seismic Design of Tall Buildings, V2.03*, Pacific Earthquake Engineering Research Center Tall Buildings Initiative, University of California, Berkeley, 2017.
3. LATBSDC, *An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region*, Los Angeles Tall Buildings Structural Design Council, California, 2017.
4. ASCE, *Seismic Rehabilitation of Existing Buildings, ASCE/SEI 41-16*. American Society of Civil Engineers, Reston, Virginia, 2016.
5. FEMA, Seismic Performance Assessment of Buildings. FEMA P-58, Prepared by the Applied Technology Council for the Federal Emergency Management Agency, 2012.
6. FEMA, Quantification of Building Seismic Performance Factors. FEMA P695, prepared by the Applied Technology Council under project ATC-63 for the Federal Emergency Management Agency, 2009.
7. ATC, *Guidelines for Nonlinear Structural Analysis for Design of Buildings: Part I – General,* NIST GCR 17-917-46v1, 2017.
8. ATC, *Guidelines for Nonlinear Structural Analysis for Design of Buildings: Part IIa – Steel Moment Frames,* NIST GCR 17-917-46v2, 2017.
9. ATC, *Guidelines for Nonlinear Structural Analysis for Design of Buildings: Part Ib – Concrete Moment Frames,* NIST GCR 17-917-46v3, 2017.
10. Lignos, D.G., Harloper, A., Elkady, A., Hamburger, R., Deierlein, G.G. "Revised ASCE-41 Modeling Recommendations for Moment-Resisting Frame Systems," Proc. 11NCEE, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.